High-Efficiency Steam Electrolyzer

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Objectives

- Develop a highly efficient steam electrolyzer for distributed hydrogen production
- Utilize natural gas as an anode depolarizer to reduce electricity consumption
- Demonstrate prototype electrolyzers with successively higher hydrogen production capacities in the laboratory
- Demonstrate a 5-kW electrolyzer for proton exchange membrane (PEMFC) vehicle refueling in the field

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- Q. Cost
- R. System Efficiency
- U. Electricity Costs

Approach

- Optimize cathode and anode materials for enhanced electrochemical kinetics and obviate carbon deposition problems
- Study the effect of microstructure on electrode performance
- Develop tubular electrolyzer stack for pressurized operation
- Develop tube fabrication and ceramic-to-metal seal processes
- Optimize system components and engineering design and perform long-term durability testing on components and systems
- Engineer pressure vessel and electrolyzer components to maximize unit safety and lifetime
- Design, build, and demonstrate prototype electrolyzers with successively higher hydrogen production capacities and demonstrate in the laboratory (to 5 kW)
- Perform a field demonstration of a 5-kW electrolyzer for PEMFC vehicle refueling

Accomplishments

- Improved performance of anode and cathode materials by optimizing composition and coating techniques
- Explored tube fabrication techniques to develop scalable production method
- Built and demonstrated laboratory-scale electrolyzer capable of producing 700 sccm of hydrogen

- Designed new electrolyzer system targeting 1-kW hydrogen production
- Confirmed tube assembly seals in test sample withstand thermal cycling between ambient and 700°C
- Initiated collaboration with the Connecticut Global Fuel Cell Center for tube fabrication
- Completed construction of 1-kW electrolyzer engineering test bed system and pressure tested to 150 psi at 700°C (tube assemblies will be delivered in August for September test)

Future Directions

- Assemble and test 1-kW electrolyzer
- Evaluate and optimize 1-kW electrolyzer
- Perform long-term testing of components and system
- Evaluate improved anode formulations to minimize carbon deposition
- Design and build 5-kW electrolyzer
- Field test 5-kW system

Introduction

A hydrogen economy will require readily available and affordable hydrogen fuel. Current methods of hydrogen production do not fulfill these requirements. We are working on an electrolyzer system that can provide distributed hydrogen production while taking advantage of the nation's existing natural gas infrastructure. Electrolysis is a promising hydrogen production technology both because of its ability to produce pure hydrogen from water and because it does not require large, centralized plants. Unlike other technologies, the cost of hydrogen production scales well from larger to smaller systems. Electrolysis units could be widely distributed and scaled to meet the hydrogen requirements of different users such as individual households, local fueling stations and industrial facilities. A significant drawback to traditional electrolysis is the large electricity consumption required to convert water to hydrogen and oxygen. The electricity requirements mean such systems are expensive to operate. In addition, if the electricity is provided from coal or gas-fired power plants, electrolytic hydrogen production does not mitigate greenhouse gas emissions.

The concept described in this report is intended to resolve some of the problems associated with electrolytic hydrogen production. By utilizing natural gas in place of air in the anode compartment in a solid oxide electrolyzer, the electricity requirements of the system are greatly reduced. The system has the capability to produce pure hydrogen or hydrogen humidified to levels appropriate for direct use in a PEM fuel cell. With inherent electrochemical compression, the requirement for external compression for pressurization could be reduced. This technology offers numerous advantages for distributed hydrogen production for stationary and transportation hydrogen fuel cells. Our preliminary calculations indicate that using this concept, hydrogen could be produced at a cost competitive with gasoline (on a per gallon equivalent basis) while also lowering carbon dioxide emissions.

Approach

As mentioned above, natural gas is used to depolarize the anode in our solid oxide-based Natural-Gas-Assisted Steam Electrolyzer (NGASE), reducing electricity usage and therefore leading to lower cost operation. We are currently pursuing a system operating in total oxidation mode in which the steam at the cathode is reduced to hydrogen and oxide anions while the methane is oxidized at the anode to carbon dioxide and water. In this mode, hydrogen is produced on the cathode side and is easily converted to a pure hydrogen stream by condensation of the accompanying water vapor. The system could also be modified to operate in partial oxidation mode in which additional hydrogen is produced on the anode side by water-shifting the carbon monoxide produced by methane partial oxidation.

Our approach is to improve system efficiency by the judicious choice of materials and by engineering the system components to maximize durability and safety. In 2003, we are building and testing an experimental system of 1 kW hydrogen production capacity. We plan to utilize this system as a test bed for future systems while also working to optimize materials performance. We are also conducting component durability testing.

Results

Past accomplishments include demonstrating the effectiveness of the use of natural gas in the anode chamber for lowering electricity consumption. It was shown that methane provided a reduction from 1.5 volts with a conventional system (with air in the anode compartment) to 0.5 volts at 1 A/cm^2 current density. An initial test system utilizing a four-tube array was demonstrated that produced 700 sccm of hydrogen at 750°C and 35 psi of steam. Results from this system were used to generate an improved design.

In FY 2003, the continuing resolution caused delays in component procurement and system construction, and the project also experienced some personnel shifts. We have worked to design a new system that should avoid some of the problems encountered in the previous prototype while offering greater flexibility. For example, the last system was limited to operating pressures of 35 psi due to leaks in the pressure vessel. Our current engineering test bed consisting of all necessary system components minus tube assemblies (Figure 1) has been built and tested to 150 psi at a temperature of 700°C and has proven to be leak free. This system is designed to accept arrays of four tubes up to 18 inches long and can be readily modified to accept higher numbers of tubes. Thus, with minimal cost and effort, our hydrogen generating capacity could be increased without the need to build an entirely new system.

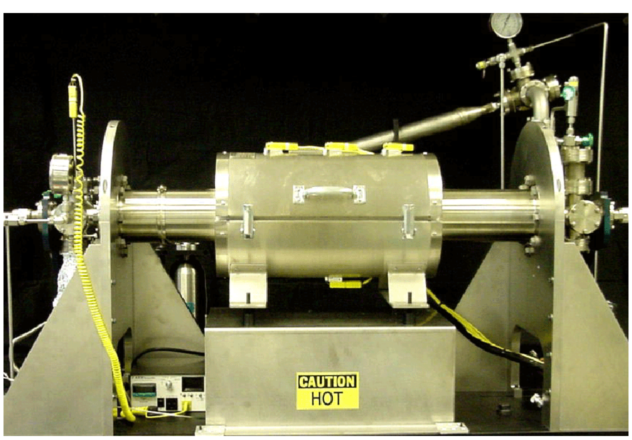

Figure 1. Electrolyzer Engineering Test Bed

In order to address the issue of carbon deposition at the anode, we have begun examining potential improved anode materials. Candidate materials with compositions approximating that of the cermet anode are screened by temperature programmed oxidation-mass spectrometry by placing powders in a quart tube and passing methane through the powder as the temperature is ramped up to 700°C. The gaseous reaction products are analyzed by a residual gas analyzer mass spectrometer. The telltale sign of carbon deposition is the evolution of hydrogen as the methane is converted to carbon and hydrogen. Materials that display reduced carbon deposition tendencies will be further evaluated by single cell testing to mimic actual electrolyzer operating conditions.

We have initiated a collaboration with the Connecticut Global Fuel Cell Center for the fabrication of tubes by an extrusion technique. The Connecticut group has more than ten years experience in tube extrusion, and this will accelerate system development efforts. After the application of electrolyte and cathode coatings, the tubes will be brazed into specially designed flexible electrical isolators (Figure 2). In the previous system, the tubes were connected in parallel, resulting in resistive losses; the new design will allow the tubes to be connected in series to allow reduced current operation. We are working with an industrial vendor to optimize these components.

Conclusions

- We have designed a new electrolyzer system that shows promise for economically attractive distributed hydrogen production.
- The electrolyzer engineering test bed has been assembled and pressure tested to 150 psi at 700°C, and we have confirmed both the pressure vessel seals and the tube assembly seals can

Figure 2. Drawing of Flexible Electrical Isolator

withstand repeated temperature cycling between ambient and 700°C.

- Our new system is designed to be flexible and scalable, allowing increased hydrogen generating capacity without the need to build a new system from the ground up.
- We have initiated a collaboration with the Connecticut Global Fuel Cell Center for fabrication of anode-supported tubes and are working with an industrial vendor for component assembly.
- Carbon deposition at the anode remains a potential challenge that we believe can be solved in the near-term by slight humidification of the methane along with applying a potential to the tubes. We are also carrying out materials studies to evaluate potential improved anode materials.
- We expect to complete the assembly of the current 1-kW electrolyzer system by late August with system testing to commence in September.
- Our system is designed to allow easy scale-up to 5 kW of hydrogen generating capacity.

FY 2003 Publications/Presentations

1. DOE Hydrogen and Fuel Cells 2003 Annual Merit Review, Oral Presentation, A.L. Vance, J.W. Trent, E.F. See, L.P. Martin, R.S. Glass "High-Efficiency Steam Electrolyzer" May 20, 2003.